

Palaeotectonic and palaeogeographic evolution of the western Tethys and PeriTethyan domain (IGCP Project 369)

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Project No. 369 (“Comparative Evolution of PeriTethyan Rift Basins”) of the International Geological Correlation Program produced a new palaeotectonic-palaeogeographic atlas of the western PeriTethyan domain. The atlas contains more than two hundred new maps and documents grouped in nine regional sets (Iberia, Polish Trough, Eastern European and Scythian Platforms, Moesian Platform, Levant, Arabian Platform, Northern Africa, NE Africa-NW Arabia, Libya-Pelagian Shelf) plus a set of reconstructions for the whole western Tethys. The area considered in the atlas stretches, from west to east, from the eastern Atlantic shores to the Urals and, from north to south, from the Baltic shield to equatorial Africa; the time span covered extends from the Late Carboniferous to the Present.

The dataset, resulting from an extensive cooperation between industrial and academic sources, is accessible interactively on a CD-ROM (Stampfli et al., 2001a) and includes legend, timetable, short explanatory notes, full references and additional supporting data. This dataset provides information on the development of the Tethyan realm in space and time. In particular, the relation between the Variscan and Cimmerian cycles in the Mediterranean realm is illustrated by numerous palaeogeographic and palaeotectonic maps.

Introduction

The PeriTethyan domain, i.e. the broad regions north and south of the Alpine thrust fronts, is a proxy of the processes which governed the break-up of Pangea, the opening of Tethyan oceanic basins and their subsequent closure and suturing. In spite of such significance, intra-plate rift/wrench basins and passive margins located on the cratons of Africa-Arabia and Europe have been neglected by most Tethyan syntheses, which instead focused on the compressional orogenic zones. The goal of IGCP Project No. 369 “Comparative Evolution of PeriTethyan Rift Basins” (1994–1999) was an integrated geological-geophysical study of rift/wrench and passive margin basins located on the northern and southern Tethyan platforms, aimed to improve constraints on the overall tectonic evolution of the Tethys orogen. More than two hundred researchers from thirty-six

countries actively took part in IGCP 369. These participants came from academia, the oil industry, geological surveys and other institutions. More than one hundred scientific publications have stemmed directly from the activities of this project. Eight independent meetings and five symposia at large international congresses were organized within the framework of the project.

The palaeotectonic-palaeogeographic atlas of the western PeriTethyan domain (Stampfli et al., 2001a), represents one of the two main end products of IGCP Project No. 369. The other one is a companion volume (Ziegler et al., 2001a) outlining the structure, stratigraphy and evolution of a number of rift/wrench basins and passive margins, which developed through time within and along the northern and southern margins of the Tethyan belt, and on the adjacent cratonic platforms. The starting assumption was that the extensional basins on the Tethyan margins preserved a detailed record of Tethyan processes. Considering that the evolution of these basins was governed by stress systems related to the opening as well as to the closure of the western Tethyan realm, and that some of them were not directly involved in the Alpine orogeny, their tectonostratigraphic record provides valuable information on the evolution of the Tethyan domain through time. The results of basin analyses carried out in the framework of IGCP 369, integrated with supplementary data from surrounding regions, provided a base for the development of a set of new plate reconstructions and supporting palaeotectonic-palaeogeographic maps contained in the CD-ROM (Stampfli et al., 2001a).

Ziegler et al. (2001a) presents the foundations upon which the atlas presented in this paper was constructed; it includes contributions on western Tethyan basin development related to processes controlling the break-up of Pangea, the progressive opening of the Tethyan system of oceanic basins and their closure during the Cimmerian and Alpine orogenic cycles. It addresses, as well, extensional tectonics that accompanied the Neogene suturing of Africa-Arabia and Eurasia. The tectonostratigraphic record of these basins, which hitherto has not been fully taken into consideration, provides new and more accurate information on the interaction between the Eurasian and African-Arabian plates through time. Opening chapters on “Dynamics of Rifting and Basin inversion” and the “Evolution of the Western Tethys Realm”, presenting a timetable for rifting activity and the opening and closure of oceanic basins and revised plate kinematic reconstructions, are followed by twenty-two papers discussing the evolution of specific basins or regions. Areas addressed range from Iberia to the Black Sea and the Uralian foreland and from North Africa to the Gulf of Aden and Northern Arabia. All papers are based on a thorough analysis of data acquired by the petroleum industry, scientific research programs and geological surveys. Much of the data presented in this author compendium have previously not been published or were not readily accessible to the general international reader.

Plate-tectonic versus continental drift

Contrary to continental drift models, which only consider displacement of continents on a sphere and so do not take into account plate boundaries, our goal during the elaboration of these new palaeotectonic reconstructions was to develop plate-tectonics constrained models. We integrated ocean spreading rates, plate buoyancy, dynamic plate boundaries, pelagic series and ophiolites occurrences and major tectonic and magmatic events.

The subsequent procedure was applied during the reconstructions of the western Tethyan realm:

- Continents: present shape and size and/or geological boundaries when applicable
- Terranes: when possible present shape was kept for geographical identification
- Continental fit: tight fits were used systematically to take care of crustal extension during rifting
- Oceanic pseudo-anomalies: for disappeared oceans and reconstruction of plate boundaries
- Spreading rates: in line with geodynamic context
- Baltica palaeo-poles: as reference for palaeo-latitudes
- Euler Poles of rotation: for each continent
- Europe as reference: fixed on the globe in its present day position

The use of Euler poles for each continent has numerous consequences, one of them being the geometry of transform boundaries; when they are known (e.g. Levant transform) the chosen Euler pole has to conform with this geometry. The other point is the maximum spreading rate that a chosen pole implies along its equator, what appears as an acceptable spreading rate close to the Euler pole is sometimes unacceptable a few thousands of kilometers away. Spreading rates were systematically calculated at the Euler equator of PaleoTethys and NeoTethys in order to check whether the figures were acceptable (below 20 cm/y).

We have combined stratigraphic, sedimentary and palaeontological data to produce subsidence curves in some key areas (Stampfli, 2000; Stampfli et al., 2001b). Subsidence analysis is a powerful tool to compare different basin histories particularly passive margins, because it allows us to characterize and constrain the timing of major geodynamic events. Palaeomagnetic and palaeobiogeographic information was also incorporated to the limit of our knowledge to constrain the location of older continents, whilst magnetic anomalies were used to constrain younger reconstructions. This multidisciplinary approach was applied to the entire globe in order to become self constrained. Nearly a hundred continents and terranes were used to elaborate the reconstructions (orthographic projection) on the GMAP Software package (Torsvik and Smethurst, 1994). We focussed our attention particularly on the Tethyan realm for which numerous continental drift models have been presented in the last thirty years, in order to see if plate-tectonic models including dynamic plate boundaries could solve some of the main geological issues. Alternate proposals were tested prior to making a selection. In the process of this we discovered that dynamic plate boundaries reported from one reconstruction to the next, give a high level of constraint, not reached by continental drift models proposed so far.

Based on the fact that a continent is nearly always attached to a larger plate, it is not a sound approach to move this continent and ignore at the same time what is happening to its plate boundaries.

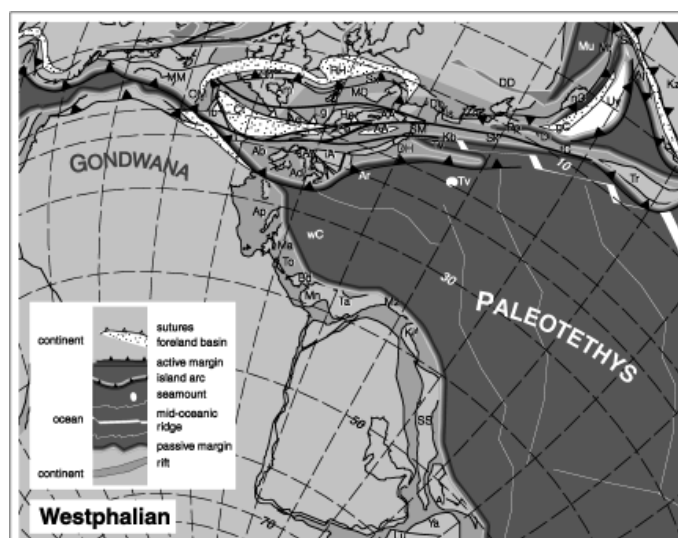


Figure 1 Late Carboniferous (Westphalian) reconstruction of the western Tethyan realm (orthographic projection, 20N/20E entered).

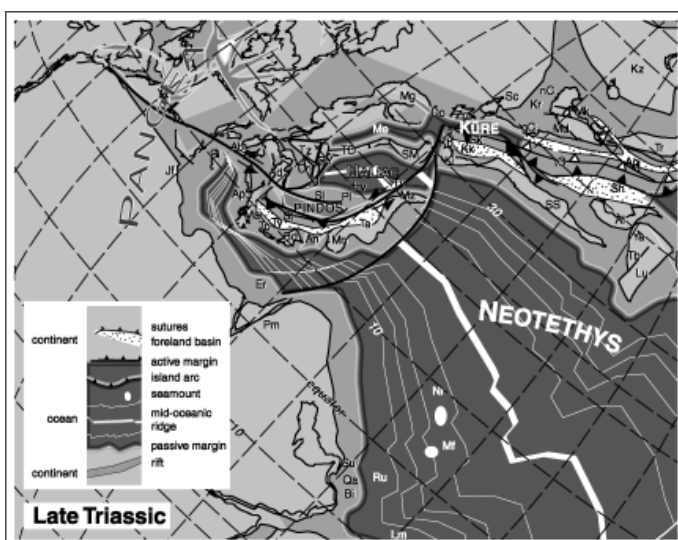


Figure 2 Late Triassic reconstruction of the western Tethyan realm (orthographic projection, 20N/20E centered).

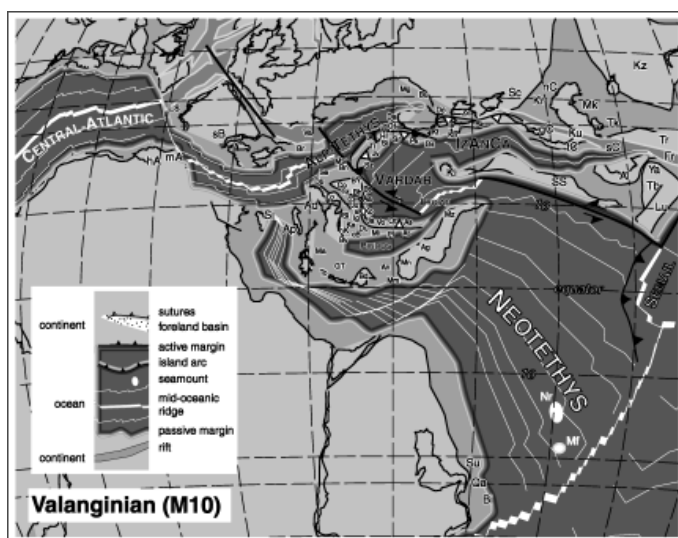


Figure 3 Early Cretaceous reconstruction of the western Tethyan realm (orthographic projection, 20N/20E centered).

Therefore, we consider that only models integrating plate boundaries can be compared to each other and that continental drift as practised by everybody since Wegener should be abandoned. Continental drift models do not allow to assess important geodynamic events such as the onset of subduction, mid-ocean ridge subduction (e.g. Gvirtzman and Nur, 1999) presence/absence of slab roll-back and related plate motion (e.g. Lithgow-Bertelloni and Richards, 1998) nor do they meet plate buoyancy criteria (e.g. Cloos, 1993).

The plate-tectonic model

The plate-tectonic model developed in Stampfli et al. (2001a) draws mostly on Ziegler et al. (2001a). Additional sources comprise, among others, Ziegler (1988, 1990) and Nikishin et al. (1996) for the evolution of the northern PeriTethyan margin, and Guiraud and Maurin (1992), Guiraud and Bellion (1995), Guiraud and Bosworth (1997) and Wilson and Guiraud (1992, 1998) for the southern PeriTethyan margin. Information from detailed palaeo-environments maps—Peri-Tethys Palaeogeographical Atlas of Dercourt et al. (2000), was partly integrated in our geodynamic framework. The following is a brief, introductory description of the large-scale plate-tectonic development of the western Tethys during the Late Carboniferous-Mesozoic times, with emphasis on the Cimmerian events. The interested reader is referred to Stampfli et al. (2001a) and Ziegler et al. (2001a) for the full dataset, including more than 200 palaeogeographic-palaeotectonic maps.

Diachronous subsidence patterns of Tethyan margins since the Early Paleozoic (Stampfli, 2000) provide constraints for palaeocontinental reconstructions and the opening of now disappeared oceans. PaleoTethys opened from the Late Ordovician to the Early Devonian, and was associated with the detachment of the ribbon-like Hun superterrane (von Raumer et al., 2001) along the northern margin of Gondwana. NeoTethys opened from Late Carboniferous to late Early Permian, starting with Australia and progressing to the East-Mediterranean area (Stampfli et al., 2001b). This opening was associated with the detachment and the drifting of the Cimmerian superterrane away from Gondwana. The final closing of PaleoTethys occurred in Middle-Late Triassic times.

Northward subduction of PaleoTethys triggered the opening of back-arc oceans along the Eurasian margin from Austria to the Pamirs. The fate of these Permo-Triassic marginal basins was quite different from area to area. Some closed during the Cimmerian collisional events (Karakaya, Agh-Darband, Küre), whilst others (Meliata-Maliac-Pindos) stayed open and their delayed subduction induced the opening of younger back-arc oceans (Vardar, Black-Sea).

The onset of NeoTethys subduction followed the Middle to Late Triassic Eocimmerian event, and created a strong slab-pull effect, which contributed towards the break-up of Pangea, involving the opening of the Central Atlantic ocean in Early Jurassic time. The Atlantic break-up extended eastward into the Alpine Tethys in an attempt to link up with the Eurasian back-arc oceans. The diachronous subduction of the NeoTethys mid-ocean ridge was most likely responsible for major changes in the Late Jurassic to Early Cretaceous plate tectonics and the final break-up of Gondwana.

Figure 1 shows a Late Carboniferous (Westphalian) reconstruction in which the northward subduction of PaleoTethys is responsible for the widespread Late Carboniferous calc-alkaline intrusions and volcanism in the Variscan Alpine domain. Slab roll-back produced a general collapse of the pre-existing Variscan cordillera. Closure of the Paleo-Tethys was achieved in post-Namurian times north of Africa but is diachronous eastward. East of a paleo-Apulian

promontory, subduction continued into the Permian and generated the opening of the Meliata-Maliac-Pindos and Karakaya-Küre marginal oceans.

As shown in Figure 2 (Late Triassic time) concomitant Late Permian opening of the marginal Meliata-Maliac-Pindos oceans (within the Eurasian margin) and NeoTethys (within the northern Gondwana margin) accelerated the closure of the PaleoTethys in the Dinaro-Hellenide region. Middle Triassic mélange found in Greece points to a final closure of this Paleozoic ocean at that time (Eocimmerian event). In Turkey, the collision of the Cimmerian terranes with the Eurasian margin was more complex due to the presence of oceanic plateaus and Marianna type back-arc basins between the two domains.

Figure 3 is an Early Cretaceous reconstruction showing the complex obduction/collision of the Vardar plate with its surroundings. First, the Late Triassic-Early Jurassic intra-oceanic subduction of the Meliata-Maliac ocean generated the opening of the Vardar marginal ocean, which was partially obducted during the Late Jurassic onto the Dinaro-Hellenic area. Its subsequent NE-directed subduction generated the collision of an intra-oceanic arc with the Austro-Carpathian and Balkanide areas in late Early Cretaceous times. Postulated subduction of the NeoTethyan mid-oceanic ridge south of Iran is interpreted to have triggered a strong transtensional stress responsible for the break-up of Gondwana and the opening of a north-south oceanic realm from the Mozambique area up to the NeoTethys ridge. The rotation of East-Gondwana with respect to Africa was responsible for intra-oceanic subduction within the NeoTethys and the onset of spreading of the Semail Marianna-type back-arc basin.

Palaeogeography

The detailed palaeogeography of the PeriTethyan areas supports the evolutionary model proposed above. This model is also constrained by palaeomagnetic data for the large continental areas before the Jurassic, and by magnetic anomalies in the Atlantic and Indian oceans starting from the Jurassic. But inside the Tethyan realm, the palaeotectonic evolution of small terranes (Figure 4) will be a matter of discussion for a long time. Yet, their geological history and palaeogeographic affinities with respect to surrounding PeriTethyan

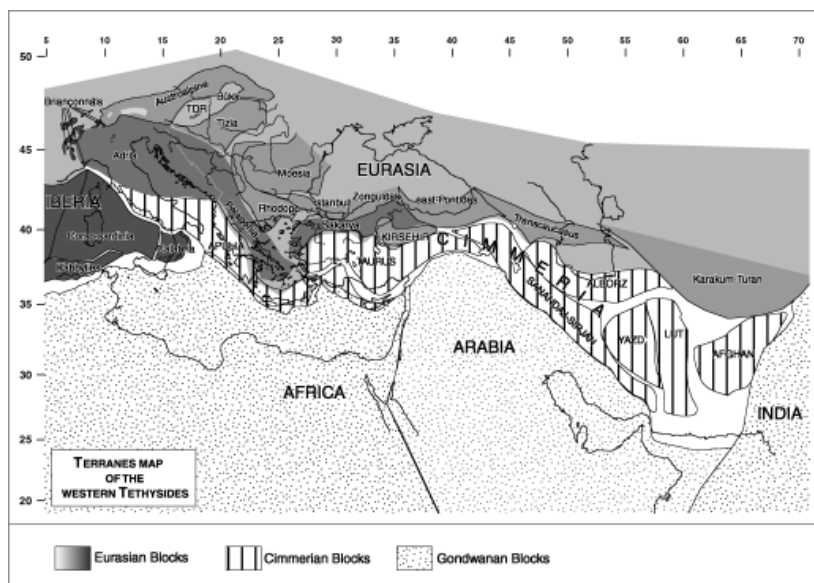


Figure 4 Terranes map of Tethyan realm. The Cimmerian terranes (vertical hatching) are found in between the Gondwana domain (Africa, Arabia and India) and the Eurasian domain. Along the southern border of the latter numerous terranes are also found and are characterized by the Variscan deformation, which is not found in the Cimmerian blocks.

areas can be traced and defined in such a way that their drift history will help to constrain this model. So this model is a plate tectonic model (with built-in plate boundaries geodynamically consistent from one reconstruction to the next) and not a continental drift model, any new kinematic information (e.g. onset of rifting, onset of subduction) places additional constraints and allows elimination of alternate solutions. The sets of regional palaeogeographic maps presented in the CD and the information used to construct them (stratigraphic charts, subsidence curves, sedimentological analysis, etc.) provided very useful information to constrain the plate tectonic models. In this scheme, all the Cimmerian terranes (from Apulia to South Tibet) are regarded as Gondwana derived and devoid of any Variscan deformation. Up to their Permian detachment from Gondwana, they represent the northern passive margin of this continent. During the Triassic they were involved in the Eocimmerian phase of Paleotethys closure and were subsequently dispersed creating an apparent duplication of the Paleotethys northern margin during the Alpine orogenic events.

Figure 5A presents a general Late Permian palaeogeographic map for North Africa. It shows the rift, which opened between

Africa and East Gondwana (Somalia Basin) in Permian times, linking southward with the Karroo system. This rift was an aborted branch of NeoTethys whereas another westward branch extended up to the East-Mediterranean area where the rift shoulder is transgressed following the onset of its thermal subsidence. Figure 5B shows in more detail the development of the passive margin on the same shoulder during the Early Ladinian in the Levant-Egyptian region, where transgression of the shoulder is even more evident.

Figure 6 presents a palaeogeographic map for the Arabian peninsula for Late Jurassic times. It shows a more mature NeoTethys passive margin development around this area, as well as active rifting in Yemen linked to sea floor spreading processes in the Mozambique-Somalia areas and the onset of separation of Western and Eastern Gondwana.

Figure 7 presents an example of supporting data attached to palaeogeographic set of maps for the Moesian platform. It shows the complex and multistage development of the Balkan rift zone and its inversion in Cretaceous time. The Balkan rift is an aborted branch of the Meliata back-arc basin, which separated the Rhodope (Strandzha) block from Moesia in the Middle Triassic. Inversion of

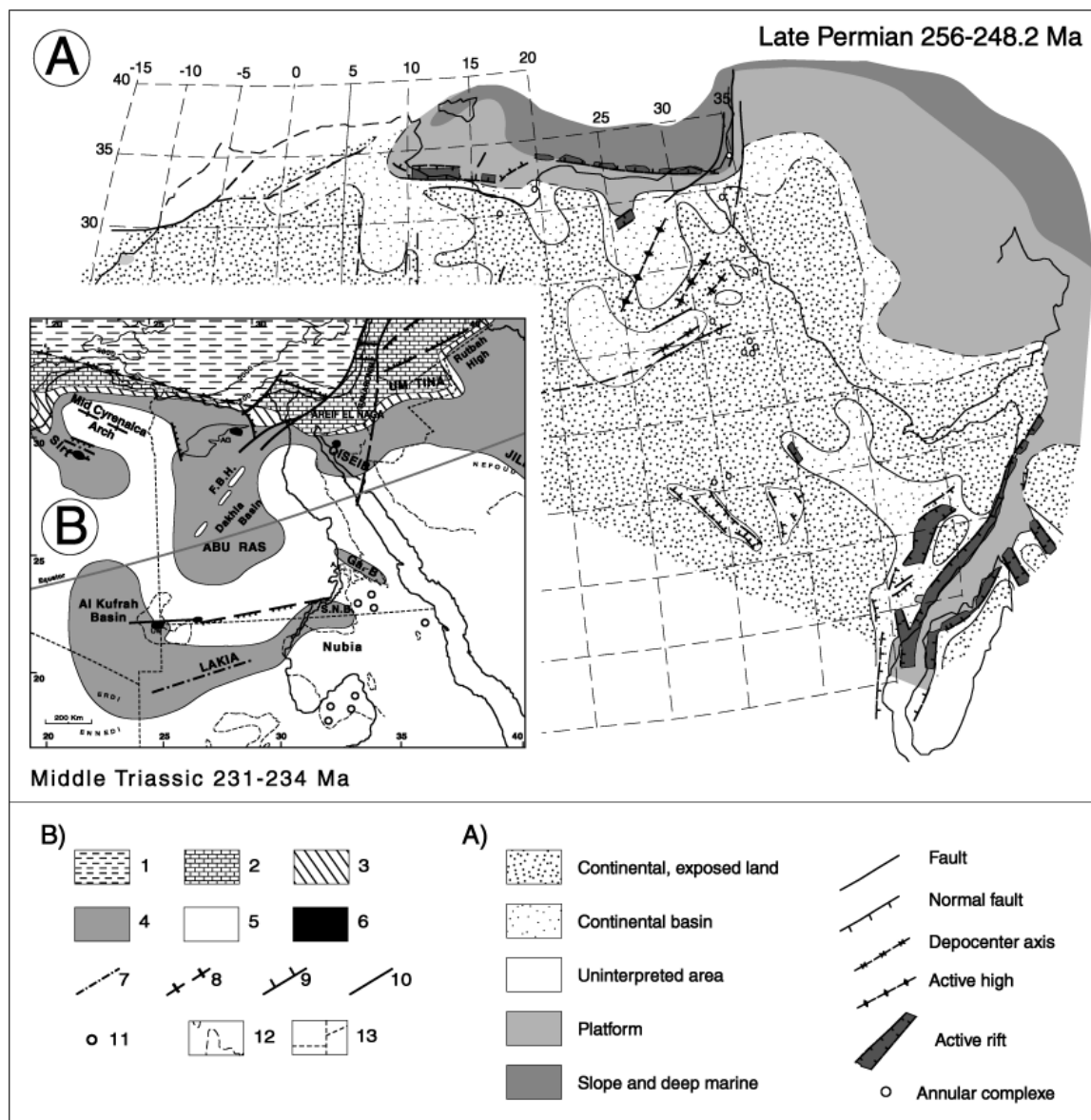


Figure 5 A—General palaeogeographic map for North Africa for the Late Permian (orthographic projection 15N/20E centered);

B—Early Ladinian map of the Levant-Egyptian region. 1, Deep basin; 2, carbonate platform; 3, mixed platform (carbonate and siliciclastic facies); 4, fluvial-lacustrine environment; 5, exposed land; 6, volcanics; 7, depocenter; 8, uplifted arch; 9, active normal fault; 10, fault; 11, alkaline anorogenic complex; 12, present-day Precambrian basement-sedimentary cover limit; 13, political boundary.

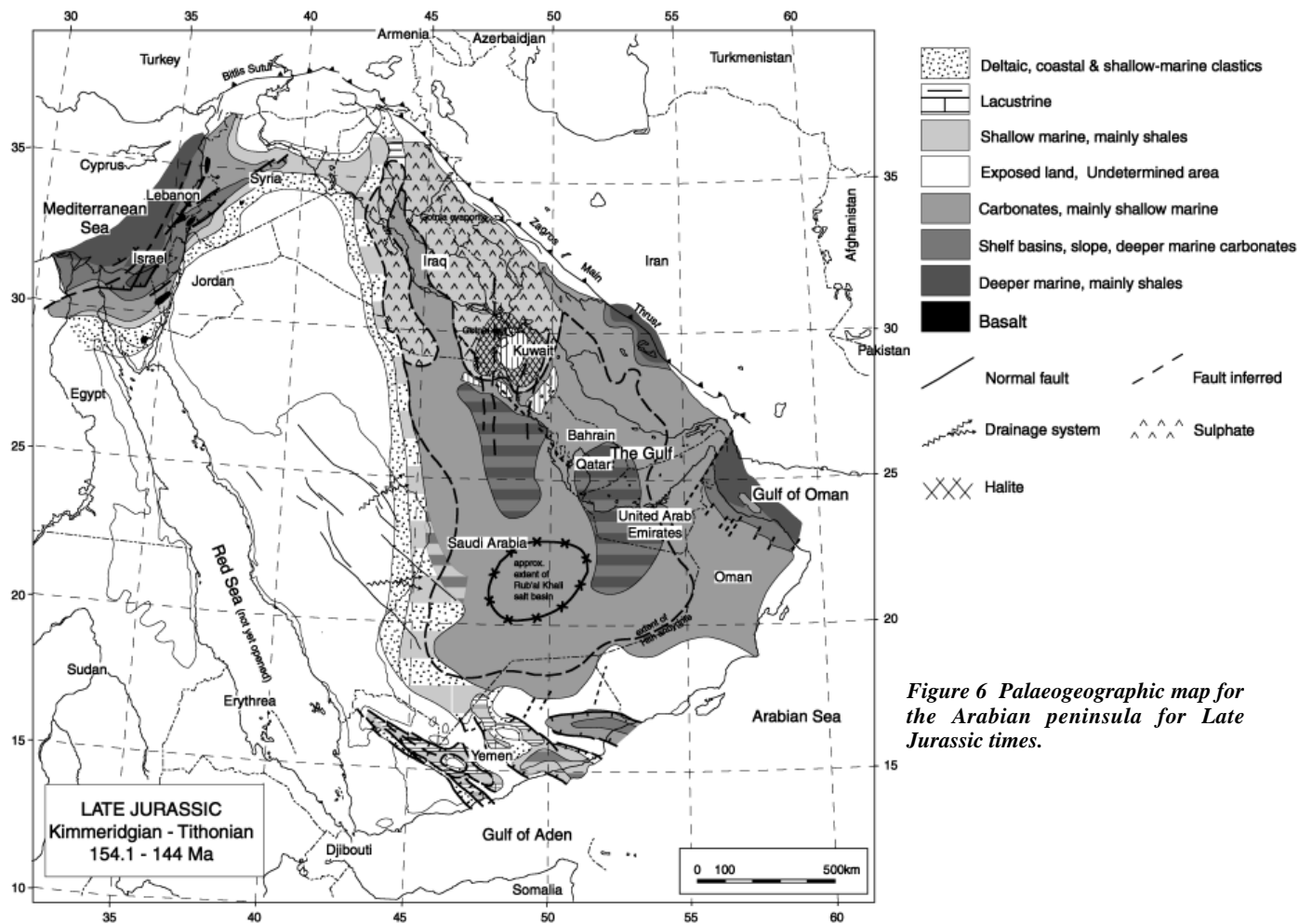


Figure 6 Palaeogeographic map for the Arabian peninsula for Late Jurassic times.

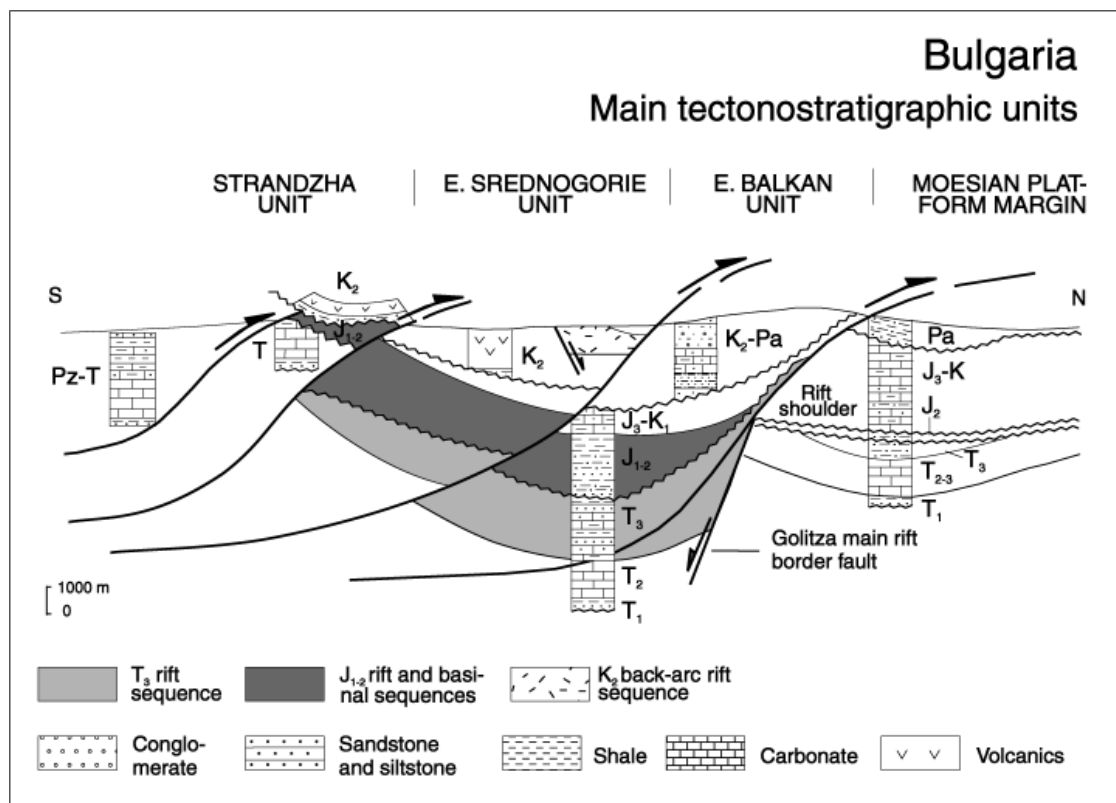


Figure 7 Main tectono-stratigraphic units of the Balkan domain.

this rift started during the Late Jurassic due to the closure of the Meliata ocean and the collision of the oceanic Vardar plate with Moesia. The subsequent northward subduction of the Vardar ocean created the Late Cretaceous Srednogorie volcanic arc, extending eastward to the Black-Sea, regarded as a back arc basin due to the northward subduction of the Izmir-Ankara-Vardar oceanic slab. Closure of the Vardar ocean occurred in Paleogene times and a new phase of inversion created the final structure of the Balkan chain.

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References

- Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M. F., Cadet, J. P., Crasquin, S., and Sandulescu, M., eds, 2000, *Peri-Tethys Palaeogeographical Atlas*, Paris.
- Cloos, M., 1993, Lithospheric buoyancy and collisional orogenesis: subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts: *Geological Society of America Bulletin*, v. 105, pp. 715–737.
- Guiraud, R., and Bellion, Y., 1995, Late Carboniferous to Recent geodynamic evolution of the West Gondwanian, cratonic Tethyan margins, in Nairn, A.E.M., Ricou, L.E., Vrielynck, B. and Dercourt, J., eds., *The Ocean basins and Margins*, vol. 8: *The Tethys Ocean*: Plenum Press, New York, pp.101–124.
- Guiraud, R., and Bosworth, W., 1997, Senonian basin inversion and rejuvenation of rifting in Africa and Arabia: synthesis and implications to plate-scale tectonics: *Tectonophysics*, v.282, pp.39–82.
- Guiraud, R., and Maurin, J. C., 1992, Early Cretaceous rift of western and central Africa: an overview: *Tectonophysics*, v.213, pp.153–168.
- Gvirtzman, Z., and Nur, A., 1999, plate detachment, asthenosphere upwelling, and topography across subduction zones: *Geology*, v. 27, pp. 563–566.
- Lithgow-Bertelloni, C., and Richards, M. A., 1998, The dynamics of Cenozoic and Mesozoic plate motions: *Reviews of Geophysics*, v. 36, pp. 27–78.
- Nikishin, A., Ziegler, P. A., Cloetingh, S., Stephenson, R. A., Furne, A. V., Fokin, P. A., Ershov, A. V., Bolotov, S. N., Korotaev, M. V., Alekseev, A. S., Gorbachev, V. I., Shipilov, E. V., Lankreijer, A., Bembinova, E. Yu., and Shalimov, I. V., 1996, Late Precambrian to Triassic history of the East-European Craton: dynamics of sedimentary basin evolution: *Tectonophysics*, v.268, pp.23–63.
- Stampfli, G. M., 2000, Tethyan oceans, in Bozkurt, E., Winchester, J.A., and Piper, J.D.A., eds., *Tectonics and magmatism in Turkey and surrounding area*, Volume 173, *Geological Society of London, Special Publication*, pp. 163–185.
- Stampfli, G. M., Borel, G., Cavazza, W., Mosar, J., and Ziegler, P. A., eds., 2001a, *The Paleotectonic Atlas of the Peri-Tethyan Domain* (CD-ROM): European Geophysical Society (http://www.copernicus.org/EGS/egs_info/book.htm).
- Stampfli, G. M., Mosar, J., Favre, P., Pillevuit, A., and Vannay, J.-C., 2001b, Permo-Mesozoic evolution of the western Tethys realm: the NeoTethys East-Mediterranean Basin connection, in Ziegler, P.A., Cavazza, W., Robertson, A.H.F. and Crasquin-Soleau, S., eds., *Peri-Tethyan Rift/Wrench Basins and Passive Margins*: National Museum of Natural History, Paris, *Memoir n.186*, pp. 51–108, in press.
- Torsvik, T. H., and Smethurst, M. A., 1994, Geographic mapping and paleoreconstruction package (GMAP). Software description and examples of paleoreconstructions.
- Von Raumer, J. F., Stampfli, G. M., Borel, G. D. and F. Bussy, F., 2001, The organization of pre-Variscan basement areas at the north-Gondwanan margin. *Int J Earth Sci (Geol Rundsch)*, DOI 10.1007/s005310100200.
- Wilson, M. and Guiraud, R., 1992, Mesozoic-Cenozoic magmatism associated with the West and Central African Rift System: *Tectonophysics*, v.213, pp.203–225.
- Wilson, M., and Guiraud, R., 1998, Late Permian to Recent magmatic activity on the African-Arabian margin of Tethys, in McGregor, D.S., Moody, R.T.J. and Clark-Lowes, D.D., eds., *Petroleum Geology of North Africa*: Geological Society of London Special Publication 132, pp.231–263.
- Ziegler, P. A., 1988, Evolution of the Arctic-North Atlantic and Western Tethys: *American Association of Petroleum Geologists Memoir* 43, p. 198.
- Ziegler, P. A., 1990, *Geological Atlas of Western and Central Europe* (2nd edition): Shell International Petroleum Mij. B. V., The Hague, pp. 232.
- Ziegler, P. A., Cavazza, W., Robertson, A. H. F. and Crasquin-Soleau, S., eds., 2001a, *Peri-Tethyan Rift/Wrench Basins and Passive Margins*: National Museum of Natural History, Paris, *Memoir n.186*, 782 p., in press.
- Ziegler, P. A., Cloetingh, S., Guiraud, R. and Stampfli, G., 2001b, Peri-Tethys platforms: constraints on dynamics of rifting and basin inversion, in Ziegler, P. A., Cavazza, W., Robertson, A. H. F. and Crasquin-Soleau, S., eds., *Peri-Tethyan Rift/Wrench Basins and Passive Margins*: National Museum of Natural History, Paris, *Memoir n.186*, pp. 9–49, in press.